WORLD LAUNCHER REVIEW 2015-16

A comprehensive guide to the world's launch vehicles and launch market

Seradata

CST

WORLD LAUNCHER REVIEW

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ABOUT

Commercial Space Technologies Limited (CST) has been a general consultancy in the space field for over 30 years, delivering in-depth technical analysis to government departments, space agencies, private companies and the insurance sector. It has a base of operations in London and a representative office in Moscow, with a native Russian speaking staff. The expertise and contacts that CST has developed during its extensive period of operations, has enabled it to adeptly provide trading and management services between Western and Russian space related industries and institutions. CST also brokers the services of Russian and Ukrainian launchers to an international clientele, supporting its customers through contractual milestones, customs and integration procedures and launch campaign logistics. CST has facilitated the launch of 33 satellites, on 5 different launch vehicles, from 3 different launch sites. For more information go to: http://commercialspace.co.uk

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WORLD LAUNCHER REVIEW 2015-16 Contents

1. THE MARKET

An assessment of the current world launching market, as well as forecasts of this market's future development, through the analysis of spacecraft launch statistics over a 10-year period (from the beginning of 2005 to the end of 2014) is carried out in **Sub-section 1.1**. All of the data has been compiled using the Seradata 'SpaceTrak' database /1/.

This data has been processed to analyse its trends which then enable forecasts to be made regarding world launches and the numbers of spacecraft to be launched for the period 2015-2020, while also taking into account the probable drivers that will have an influence on the market in this timespan. A definition of these market drivers and an assessment of their specific influences are made in **Sub-section 1.3**.

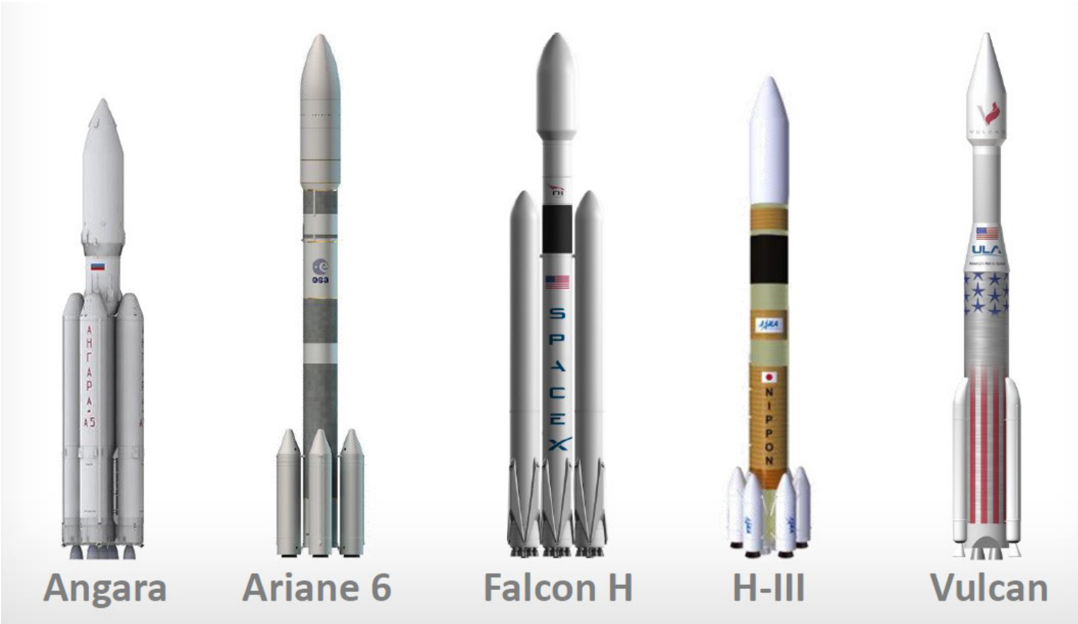

Fig. 1-1 New and proposed launch vehicles are aimed at successfully competing in the world launch market

Courtesy: Khunichev, ESA, SpaceX, IHI, ULA via Arianespace

1.1 The Spacecraft Market

To demonstrate the demand for spacecraft launch services, the data enclosed in this review is divided into assessed years and represented in the form of tables. To provide a clear image of the trends depicted in these tables, some of the data is also presented as charts.

These tables separate launched spacecraft by their orbit (or trajectory), purpose, mass class and operator. It should also be noted that the same mass classes for LEO and GEO satellites also have different mass ranges, e.g. a 4-ton satellite would be medium class for a low-orbital spacecraft but heavy class for a geostationary satellite.

Whilst this part of the market overview is directly relevant to assessing spacecraft demands for launch services; processing the same data also allows for the study of certain spacecraft-relevant features that influence trends across the world's current launch vehicle inventory. This data has been presented by assessing the methods which launch service providers use to accommodate for the launch of single or multiple spacecraft at a time. Some insights into the launching industry have also been derived from data on the purpose of launches (either commercial or state funded) and launcher ownership (i.e. which specific nations or international companies/organisations they belong to).

All of the analysis in this section uses raw launch data from SpaceTrak, and thus includes all orbital launch attempts, both successes and failures. The reasoning for this is that all launches, even those that fail to deliver spacecraft to their intended orbits, have had investment that makes them commercially relevant and thus adds to the overall model of the launching market.

*Editor's note on **Section 1**: The data in the tables for this section may fall short or exceed that of their totals as some spacecraft designations may have been omitted for commercial relevance and others may have overlapped in their definition.*

The data presented in **Tables 1.1-1.4**, quantitatively present the current global market for spacecraft launches, as well as allowing for some inference into how these figures have changed over the past ten years. One can see that the total numbers of spacecraft launched have increased from 79 in 2005 to 302 in 2014 (an increase of 3.8 times). This increase was however, not proportionate over the last 10 years: two sharp 'jumps' took place in 2006 (from 79 to 115) and 2012-2014 (from 139 to 302). This trend is also clearly visible in **Chart 1.1-4**, with a comparatively gradual increase in the total numbers of spacecraft launched, culminating in a sharp increase from 2012-2014 where the figures approximately double.

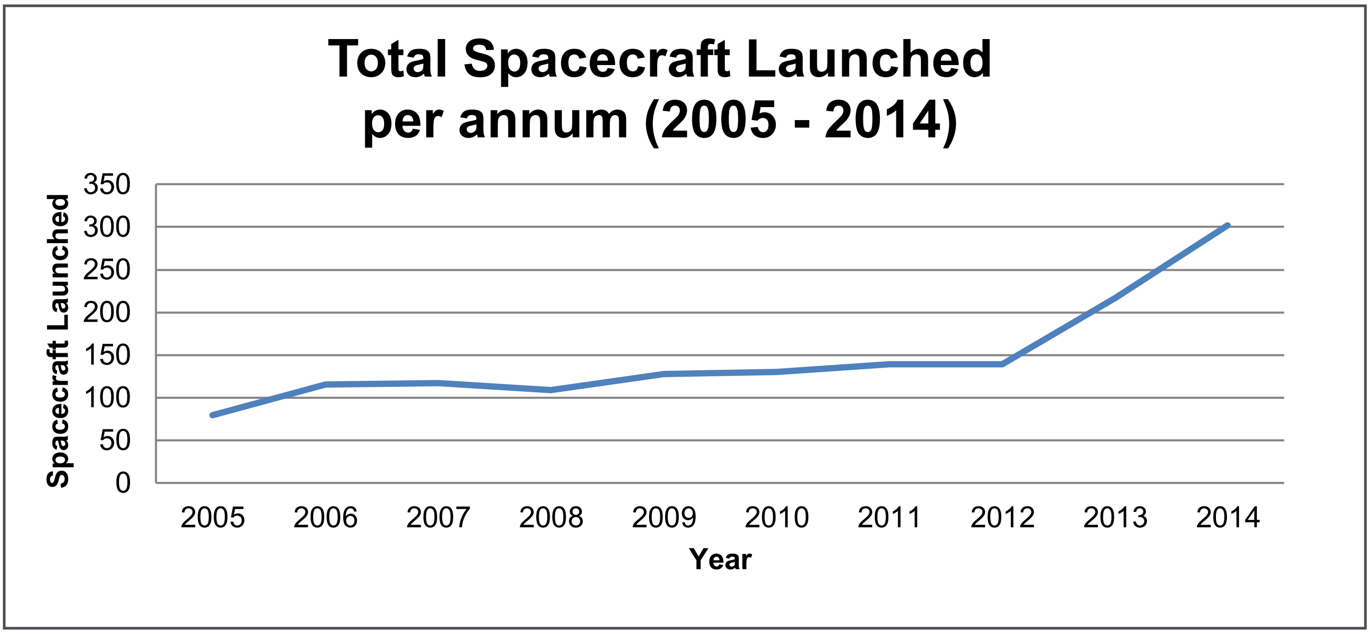

Chart 1.1-4 Total numbers of Spacecraft launched from 2005-2014, depicting a distinctive spike in numbers from 2012 onwards

The first above average rise in the total amount of spacecraft launched was in 2006, with an almost proportional increase in the numbers of spacecraft launched across almost all major LEO and GEO orbits and masses, excluding medium and heavy LEO satellites, navigation satellites and probes, **Tables 1.1 and 1.3**.

This rise in 2006 suggests that a recovery was underway from the visible downturn in annual launches that had taken place from 2001-2005 (e.g. attempted orbital launches had decreased from 85 in 2000 to 55 in 2005).

The Increase in LEO Spacecraft launched in 2006

An explanation for the 2006 spike in mini (≤100kg) and small (up to 2 tons) LEO satellites can be offered when looking at the data from **Table 1.1-2**. Within this data one of the most prominent sectors to increase in numbers were that of scientific, educational and technology spacecraft **(Chart 1.1-3)**, mostly launched from the US and international countries outside of the top four space faring nations (China, Europe, Russia and USA), **Table 1.1-4**. This trend within the US can be almost entirely attributed to an increase in nano-class (1-10kg) satellite numbers. This class of satellite has been in existence for over 15 years, originating from California Polytechnic State University, USA, in early 2000.

The concept employs small mass (<10kg), standardized dimensions (comprised of 10cm x 10cm x 10cm modules) and readily available consumer electronics to drastically reduce development costs /2/. For these reasons, CubeSats are often built as a low-cost means to train students, seed spacecraft manufacturing start-ups, test components in space, and facilitate the passage of new nations into the space industry /3/. By 2006 the CubeSat concept had been in existence for 6-7 years and was beginning to gain popularity in the U.S, which partly accounts for the 2006 spike in scientific, educational and technology spacecraft seen in **Chart 1.1-3**. Meanwhile in the international community, Japan had also launched a series of nano-class satellites, while Taiwan had launched a constellation of six mini research satellites called FORMOSAT,

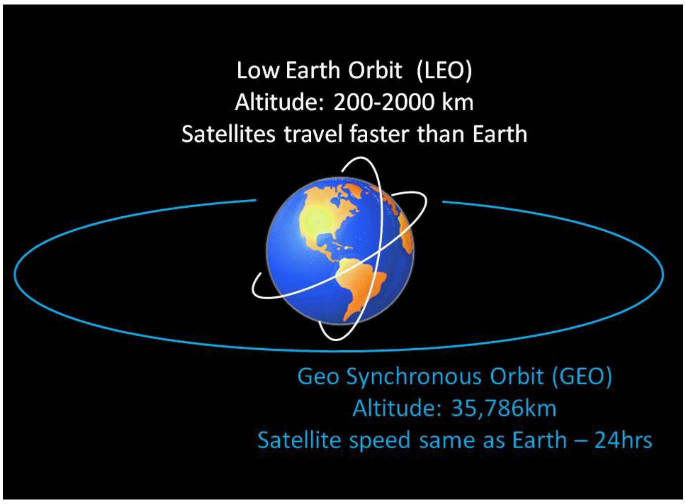

Fig. 1.1-1 Geostationary/Geosynchronous Earth Orbits (GEO) and near-polar Sun-synchronous LEO orbits remain the most important satellite designation orbits.

Courtesy: Ardusat via vox.com

2. TECHNOLOGY AND RELIABILITY

Launch vehicles and new derivatives being developed for use in the near future contain mainly proven reliable technologies to launch various payloads into space. New technologies are however being introduced (such as a reusable first stages), under the influence of how effectively they cater to customers' demands for lower cost launches and flexibility in respect to availability and payload class.

The designs of current launch vehicles have to be assessed by their proficiency towards meeting these demands for launching missions with flexibility and at an acceptable price.

The probability of a mission's success and the likelihood of a customer choosing a particular launch vehicle is strongly dependent on its reliability. No normal customer wants to see their spacecraft either catastrophically destroyed (**Fig. 2.0-1**), or left stranded in the wrong orbit. Apart from cost/launch price, reliability is normally the main reason for a launch vehicle's selection. Reliability also plays a major role in launch service supply and flight availability, a launch vehicle type will often experience a stoppage in flights after a launch failure while an investigation proceeds.

While flight experience is probably the most important factor in a launch vehicle's reliability, with early launches being especially prone to failure (maiden flights of brand new rocket designs introduced since 1990 have failure rates of 50%) /1/, the different launch vehicle technologies employed also have a major impact on reliability and this has been separately assessed in Sub-section 2.2.

Fig. 2.0-1 When a launch goes wrong, the results can be explosive. Surprisingly some CubeSats were actually recovered intact from this Antares launch explosion on October 28, 2014.

Courtesy: NASA TV

2.1 A Review of Applied Launcher Technologies

The basic reaction principle used in current rocketry for creating thrust is common amongst all launch vehicles (although other methods employing ground boosting facilities or space elevators are being studied for future applications). Using the reaction principle to accelerate a spacecraft payload to orbital velocity is achieved in various ways.

Launching methods

The initial lift-off of a launch vehicle for delivering a payload into orbit can be provided by two main methods. One method is the launch of a launch vehicle under its own thrust, from either a launch pad on land or a floating platform or submarine from the sea. The other method includes the preliminary transport of a launch vehicle up to a certain altitude via a carrier aircraft, from which the launch vehicle takes off. In this instance the combination of carrier aircraft and launch vehicle is called an 'air-launch system', whilst the method itself is termed 'air launch'. Both conventional and air-launch methods have their own features which influence both launch cost and reliability, and therefore must be assessed along with their technologies.

Launcher recoverability

An advanced option in terms of launcher technology is the use of launch vehicles' (or systems') with partial recoverability, which offer repeated use of their lower stages. This technology is currently at the stage of design, development and initial flight testing but, since it is aimed at a significant reduction in launch costs it merits a mention. Furthermore, while it is premature to assess the possible influence of this new technology on launcher reliability, it can be predicted that after some initial reliability issues that is associated with the infancy stage of all novel technology, this could lead to an increase in launcher reliability in the long term.

This could be a possibility for two reasons, firstly, the recovery of any hardware allows for a greater chance of identifying and rectifying minor faults that may not always result in a full failure; and secondly, any hardware built to be reused would assumedly have stricter quality control measures than those instated for conventional expendable launcher concepts.

Propellant technologies

Launch vehicles utilizing either of the main launching methods would use one of two main technologies that involve burning fuel and oxidiser in their main propulsion units. These are either in the form of solid propellants in which the oxidiser and fuel are mixed together, or in the form of liquid propulsion using a bi-propellant combination of fuel and oxidiser. The simplest engines of this type can be pressure fed, while more powerful versions use turbo-pumps driven via different open and closed cycles, including the use of a gas generator (**Figure 2.1-1)**, staged-combustion or expander cycles.

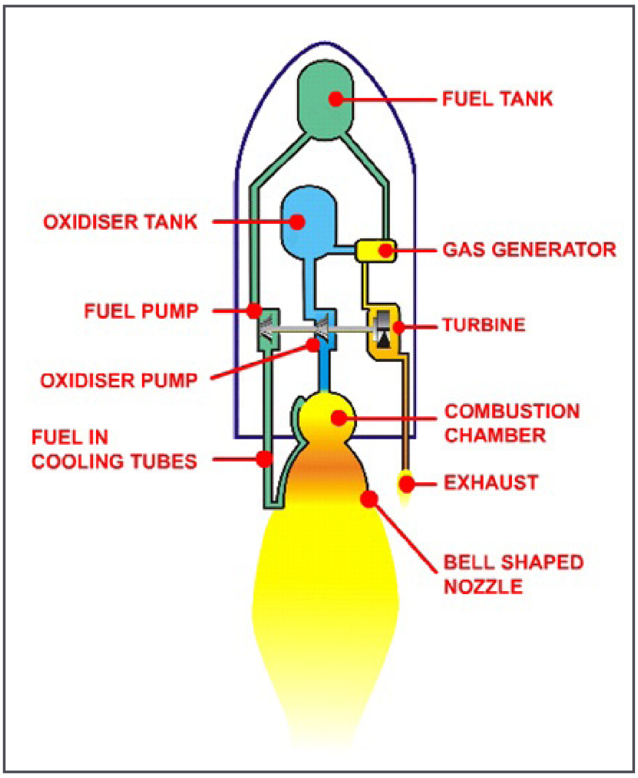

Fig. 2.1-1 Simplified diagram of a Gas Generator open cycle rocket engine.

Courtesy: Airclaims/Seradata

There are other technologies using solid fuel and liquid oxidiser in hybrid rocket systems, or mono-propellants, in which a single component contains all the chemical agents required for combustion, although neither of these are currently applied in the main propulsion units of launch vehicles. The technologies involved in operating the two main propulsion types strongly influence the cost of manufacturing the corresponding launch vehicle, as well as its reliability. For this reason they are also assessed in this section.

In liquid propulsion one or both of the propellants can be liquefied gases, known as 'cryogenic propellants' and the technology involved is called 'cryogenic propellant technology'. The application of this technology, alongside other liquid propellants with high-boiling point (storable) components, has a strong influence on the performance and operational features of the launch vehicle, and therefore on its costs and reliability.

Launcher configurations

The design of current launch vehicles differ by their adopted configurations, which include either a tandem (consecutive) accommodation of stages, a parallel configuration of stages, or a combination of both configurations, in which different propellant varieties can also be used. The number of stages and staging events can reduce reliability and increase manufacturing and integration costs.

Similarly, the number of rocket engines on an individual stage can affect reliability. Generally, the more engines a rocket has, the greater the chance of an inflight shutdown. However, having more engines can actually result in a greater performance redundancy (the remaining engines can take up the slack in the case of a shutdown - assuming it is a contained failure). This feature was demonstrated during an ISS resupply mission on Falcon 9 on 8 October 2012 when one of the launcher's nine main engines was forced to shut down during launch. This did not halt the main launch mission and the Dragon cargo spacecraft still docked successfully with the ISS, albeit at the expense of a secondary satellite payload.

The configuration is directly influenced by the energetic efficiency and thrust of the chosen engine and its propellants. For example, solid rockets normally require more stages to achieve a given payload to orbit than liquid propellant types.

Upper stage and spacecraft orbit raising technologies

A commonly adopted technology which meets a broad range of market demands for launching spacecraft into medium, high-elliptical and geostationary orbits, as well as escape trajectories, is the use of a specially designed upper stage. Some upper stages are also able to perform several main engine restarts, allowing them to carry and deposit multiple payloads into different orbital altitudes and inclinations during the same launch. This feature is ideal for rideshare and cluster missions, which represent the methods currently adopted by launch service providers to cater to the ever growing market demands of small- down to nano-sized spacecraft (see Sub-section 1.2).

An upper stage is generally developed separately from the launch vehicle in which it is used (the combination of launch vehicle and upper stage can also be referred to as a 'launch system'). The application of these upper stages have an influence on the price of launch, while the technology applied in these upper stages (in particular, the type of propellant), contributes to the reliability of the mission. All of this technology is assessed jointly within the general assessment of the technology within an upper stage.

New satellite technologies have implications for launch vehicle providers. For example, highly efficient electric propulsion is increasingly being used and is included in this assessment (see Sub-section 1.1).

Control/Guidance system and production technologies

The in-flight control/guidance technologies used in current launch vehicles and upper stages, are conceptually similar. For instance,

2.1.4 Air-Launch and partial recovery technologies

The use of a common, heavy-lifting, carrier aircraft for air-launch technology seems feasible without serious difficulties, although certain problems can arise with the separation of the launch vehicle from the carrier aircraft, and during the launcher's air ignition and its insertion into an ascent trajectory, especially if the launcher is of significant mass.

There is currently only one operating air-launch system, the US Pegasus small launch vehicle (**Figure 2.1.4-1**), although a number of similar projects are currently under development.

As shown in various studies (such as /13/), an air-launch system can be more profitable than a 'common' surface-based launch vehicle of the same payload capability, if the chosen carrier aircraft is used in an optimum manner with a high flight rate.

This was not the case for Pegasus, which partially explains the low economic efficiency of this system and hence its high launch price relative to its competitors. Nevertheless, the system is in demand for certain missions and its achieved level of reliability appears to be of a reasonably high standard for potential clients. These results suggest that new air-launch systems, which are currently being developed, could achieve a better level of economic efficiency while also maintaining an acceptable level of reliability.

Fig. 2.1.4-1 Release of the Pegasus XL launch vehicle from its carrier aircraft.

Courtesy: Orbital ATK

It is also possible to consider a carrier aircraft as a reusable quasi-first-stage in air-launch systems, but they cannot fully compare to the technical efficiency of a first stage as they do not match the required speed or altitude.

Fig. 2.1.4-2 A full-scale engineering mock-up of the Russian Baikal fly-back booster, at the Paris Airshow-2001 in Le-Bourget.

Courtesy: Khrunichev

To provide full first stage abilities, alongside reusability, several technological concepts have been proposed. One of the simplest is the method of strap-on booster recovery via a parachute slowed splash down that was employed by the Space Shuttle, although this method is no longer used. Another method, using winged fly-back boosters or first stages, is currently under serious development (**Figure 2.1.4-2**). There is also a stage recovery method that employs a vertical soft landing technique with throttled thrust of one the stages' main rocket engines to slow the stage down to a gentle landing on special landing legs. This method is currently undergoing flight tests for the US Falcon-9 launch vehicle (**Figure 2.1.4-3**).

Although the repeated use of launcher stages promises a reduction in the expense for manufacturing new hardware, the cost of developing and mastering this technology (in any version) would inevitably be high and would only be reimbursed if the reusability feature is used sufficiently often for missions.

It is equally evident that these reusable stages carry more equipment (landing legs, wings etc), which may reduce the operational payload of a launch system. Likewise they can be more complex in design, which could decrease the reliability of the whole launch system. An assessment of this reliability level can only be carried out after practical results from these systems' operations.

Fig. 2.1.4-3 A computer image of the descending US Falcon-9R's first stage, slowing the velocity of its decent with one of its main engines.

Courtesy: SpaceX

3. COMMERCIAL LAUNCH PROVIDERS

This is a survey of the providers that are supplying launch vehicle services to the current world market on a commercial basis. Launch providers which provide only “state launch” services for military and government payloads such as the Russian Aerospace Defence Forces (VKO), the Russian Centre for On-ground Space Infrastructure (TsENKI), or the US United Launch Alliance (ULA) are thus excluded from this survey.

Those launch providers that provide both national and commercial launches (e.g. Arianespace) are included however. All the providers have to be commercially active to be included in this survey. The survey it is based on information from /1/, with some relevant updates.

A full listing of the world’s currently operated launch vehicles are described briefly in Section 4. This list includes all those launch vehicles which have been launched, at least once to date, and whose programme is still in regular operation (i.e. not cancelled), and those which are expected to start imminent operations.

Apart from commercially available launch vehicles, the launch vehicle survey also includes launchers used solely for national missions and those newly developed launchers whose future is unclear. This selection is in contrast to the launch providers section, as it considers that every active or imminent launcher has a possible commercial use.

As noted in Section 2, the upper stage is an important component of a launch system, which is used for specific mission scenarios. A brief description of currently operated upper stages is therefore added to the description of the launch vehicles that use them optionally.

The development of new launch vehicles and systems, which have a firm basis for completion in the near future (by 2020), are described briefly in Section 5. Meanwhile, less developed launch vehicle and system projects, with lesser prospects for completion, are listed with additional details in Sections 6 and 7.

Commercial launch provider review

The 15 current international launch service providers (representing either private companies or national organizations) are:

1. Antrix
2. Arianespace
3. Boeing Launch Services
4. China Great Wall Industry Corporation
5. Eurockot
6. International Launch Services
7. Kosmotras
8. Lockheed Martin
9. Makeyev State Rocket Center
10. NPO Mashinostroyeniya
11. Orbital ATK
12. Sea Launch
13. Space International Services
14. Space Exploration Technologies Inc. (SpaceX)
15. Starsem

A brief description of these providers is presented below.

The current list of commercial launch service providers mostly includes specially established launch companies/ launch vehicle operators. Sometimes these have been formed from joint-stock companies or as joint ventures. Launch providers can also be provided by special subsidiaries or even departments within the companies that manufacture/develop certain launch vehicles. As a consequence, these providers can have access to market one or more launch vehicles or even whole launch vehicle families. These providers sometimes have agreements with each other to provide launches in the event that another cannot.

The list of world launch providers is constantly changing, as certain launch vehicles are removed from operation and their service providers disappear from the market (assuming they were not supplying other launcher services in parallel).

Occasionally, prospective launch providers which have previously been viewed as having a strong likelihood of launching have failed due a lack of commercial prospects, lack of funding for their marketed launcher, or because the necessary infrastructure as not been built for financial or political reasons. An example is Alcantara Cyclone Space which has removed from the list of active or likely to become active launch providers, since the work on its launch facility in Alcantara, Brazil, has been ended, and the production of its launcher, the Cyclone-4 (Tsiklon-4), has been suspended.

3.5 Eurockot

EUROCKOT
Launch Service Provider

Eurockot Launch Services GmbH was established on 23 March 1995, in Germany, as a joint venture between the Khrunichev State Research and Production Space Center (SRPSC) of Russia and Daimler-Benz Aerospace (DASA) of Germany (now Airbus Defence and Space), to market the launch services of the Rockot small class liquid-propellant launch vehicle. The German side holds a majority shareholding in the firm with 51% of the Eurockot's shares whilst Khrunichev holds the remaining 49%. The Rockot itself is a tube launched rocket converted from the SS-19 (NATO designation) ICBM that had been in operation in the Russian Strategic Rocket Troops. Rockot is now nearing retirement given that the missiles used in the conversion are near the expiration dates of their guaranteed lifetimes.

History of Rockot launch vehicle

Khrunichev received the right to purchase the decommissioned missiles for conversion into space launch vehicles. The conversion is performed by substituting their post-boost stages with the specially developed 'Breeze-K' ('Briz-K') upper stage. Although the first test launches of the Rockot had been carried out from a missile launch silo in Baikonur in 1990, 1991 and 1994, it was recognized that a proper surface launch facility should be used for its commercial operation, and eventually one of these launch facilities presented itself, following the retirement of the Cosmos launcher, in Plesetsk.

DASA's contribution was an investment of over US$50 million in the firm. This money, which was to be reimbursed from the profits of launches, was spent mostly on upgrading and refurbishing the launch facility.

Eurockot began its marketing activity in earnest in 1997. By that time, a new larger fairing was produced and the initial 'Breeze-K' ('Briz-K') was swapped for a more compact upper stage: the 'Breeze-KM' ('Briz-KM').

The first mission of Rockot in Eurockot's colours was a successful demonstration launch of two dummy satellites on 16 May 2000. Following that, a significant number of launch contracts have been signed, mainly for small scientific satellites. The first contract was successfully executed with the launch of twin NASA/DLR Grace satellites on 17 March 2002. While most contracts have been signed with governments or international organisations (e.g. ESA), some launches have been flown for commercial LEO missions.

Currently Eurockot is continuing the commercial operation of 'Rockot', in parallel with launches servicing Russia's national launch programme, which are provided by Russian Aerospace Defence Forces. By June 2015, 'Rockot' has flown a total of 26 launches (including two initial suborbital test flights), having had three failures.

The future for Eurockot

The Russian government has recently guaranteed that a minimum of 45 decommissioned SS19 missiles would be made available for conversion to Rockots. These sourced missiles have guaranteed lifetimes up to at least 2017. However, in August 2014, the Russian Ministry of Defense announced that the Rockot would be removed from use for Russian national missions in 2016. The reason was that the launcher uses a Ukrainian-supplied control and guidance systems which may no longer be supplied given the deterioration in relations between Ukraine and Russia. However, there remains a possibility that these control/guidance systems may be replaced by Russian-built equivalents. (See /3/ for details).

Nevertheless, in addition to the core rocket, the 'Breeze-KM' upper stage also needs electronics and technical support supplied by Ukraine's Khartron Research and Production Enterprise. It has announced that this would only be supplied under the guarantee that the electronic kits will not be used on military launches /4/.

Thus, with only three or four complete Rockot standard launchers left, and given that military support of commercial operations at the launch site is likely to dwindle, it is expected that the last launch of the Rockot will now take place in 2017.

With respect to a commercially available replacement for Rockot, Khrunichev may decide to delegate the task of commercial operations of the new Angara-A1.2 small class launch vehicle to Eurockot. It has the facilities for small payload processing/pre-launch preparations, currently used for 'Rockot', which could be used in the same capacity for the Angara-A1.2. Exactly how such an arrangement would work, given that Khrunichev's commercial arm, ILS, plans to offer Angara-A1.2 launches commercially, remains to be seen.

4. CURRENTLY OPERATED LAUNCH VEHICLES

The world's launch vehicle inventory includes launchers in various states of readiness, availability and development. Some may be under development. Some may be undergoing flight tests while others may be already in operation. Similarly, some may only be available for state missions only, while others can also be used for commercial launches.

This section includes world launch vehicles and systems which are currently active i.e. those which have been launched and are expected to do so again, or those new vehicles that are expected to launch. **Launch vehicles that have been retired are not included.**

For those vehicles under development, these launchers differ in the levels of their completeness. These have been divided into those which have a firm basis for completion (which have sufficient funding, experimental support, etc.), covered in Section 5 and those that are in the preliminary stages of design development (termed 'proposed launch vehicles'), which are described in Section 6. Separate from this, in Section 7, are 'proposed very small launch vehicles' with payload capabilities of under 100kg, which, despite falling outside of the strict remit of this review, have been included as they all show signs of innovation or prospects towards evolution into larger launch vehicles.

The list of currently operated launchers include five launch vehicle families consisting of up to five variant types, and 24 separate launch vehicles and systems (the term 'launch system' refers to either an air-launch system, or an optional combination of a launch vehicle with an upper stage).

To simplify the general presentation of these launchers, they have been listed in alphabetical order. The description of launcher families will include all of the family's operational vehicle types, as well as additional variants, including those that can be used with certain upper stages. Brief descriptions of these upper stages are also incorporated. These separate upper stage descriptions are presented only for cases when they are optional components of a launch system. So for example, fully integrated upper stages such as the Centaur on the Atlas V would not be described, but the 'Breeze-M' ('Briz-M') upper stage, which can be removed for three-stage missions of the Proton-M, would be.

In order to simplify a search for launch vehicles via different payload classes, **Table 4.0-1**, lists them below. This classification by class is adopted from /1/, where it is considered that launchers with a payload capability up to 2.0 tons to LEO are Small Class, launchers with a LEO payload capability ranging from 2.0 to 10.0 tons are Medium Class and launchers with a LEO payload capability ranging from 10.0 to 25.0 tons are Heavy Class.

It is also necessary to note that some launch vehicles are conventionally attributed to the Small Class even though their payload capabilities exceed the upper limit set for this class. The reason for this attribution is that these launchers are intended mostly for launching small spacecraft with launch masses no more than two tons (their lower launch costs and other circumstances allow them to fulfil these missions). In these cases, corresponding notes have been made in **Table 4.0-1**.

Each launch vehicle is described with some basic technical information and performance figures and is provided with its unmodified reliability figures expressed as number of attempts (orbital unless otherwise noted) flown up to 31 July 2015, along with successes, failures and partial failures, which are launch vehicle related only, and have occured during the same period. A failure is based on a black and white view on whether the spacecraft was injected into its correct orbit or was not (even if it was later recovered). In this context, a 'partial' is where some spacecraft on a given launch have been successfully injected, while others have not. This classification becomes more likely with the inclusion of small secondary payloads.

Descriptions of the launch vehicles/systems and families are presented below in **Sub-sections 4.1 – 4.27**.

4.3 Ariane 5 (Europe)

Manufacturer(s)	Country of Origin
Arianespace	European Union

Launch Statistics - Data correct at 31 July 2015						
Operated Version(s)	First Flight	Total Launches	Successes	Failures	Partial Failures	Estimated Launch Price (US$m)
Ariane 5 ECA	11 Dec 2002	50	49	1	0	210-220

General Specifications					
Operated Version(s)	Class	Stages + Boosters	Height (m)	Diameter (m)	Mass (kg)
Ariane 5 ECA	Heavy	2 + 2	54.8-59	5.4	777,000

Payload Capabilities					
Operated Version(s)	Launch Site(s)	Payload to LEO (kg)	Payload to SSO (kg)	Payload to GEO (kg)	Payload to GTO (kg)
Ariane 5 ECA	Kourou, French Guiana	-	-	-	9,600 (9,100 with dual adapter)
Ariane 5 ES	Kourou, French Guiana	21,000	-	-	8,000 (7,000 with dual adapter)

Although the Ariane 5 was a new launch vehicle and a radical departure from the Ariane 1-4 series in many ways, it did share the same launch philosophy using a direct injection into GTO. That is, a direct ascent into GTO removes the need for an initial parking orbit and engine re-ignition. The choice of this flight profile was because of the near-ideal location of the launch site so close to the equator. Apart from its boost advantages from the Earth's spin, this location removed the need to significantly correct the inclination of the GTO plane before transfer. A minor inclination correction can instead take place at the apogee of the GTO using the spacecraft's own propulsion.

Large solid-propellant rocket boosters are designed to burn in parallel with the main core stage at lift off. The highly efficient first and second stages reduces the potential for failures by limiting the need for staging events, while direct injection into GTO from its near-equatoral launch site, limits the number of in-flight engine ignitions required. The vehicle is sized for launching two payloads (ideally of similar masses) simultaneously to GTO, and the overall payload is significantly larger than the payload carried by the Ariane 4 to the same orbit.

Flight History and evolution

The basic Ariane 5G launch vehicle was first launched on 4 June 1996. This launch failed due to a control system design error. The Ariane 5G went on to have two other launch related undershoot failures caused by a main stage roll induced propellant starvation (1997) and upper stage combustion instability (2001). The first commercial launch took place on 10 December 1999. The Ariane 5G version of the launcher remained in operation until December 2004.

Improvements to the payload performance and mission flexibility were made in a series of upgrades to the upper stage and main core stage via the G plus, GS, to the eventual ES and ECA variants. A final performance upgrade called the Ariane 5 ME was however cancelled in favour of developing a close, but cheaper to produce derivative of the Ariane 5 ME, the Ariane 6.

The Ariane 5G used a core cryogenic EPC stage powered by a LOx/liquid hydrogen-burning Vulcain engine. The upper stage used hypergolic propellants and used the N2O4/MMH Aestus engine. To achieve lift off, two large solid rocket EAP boosters were used. The Ariane 5G had a GTO payload of 6,800kg (5,900kg for a dual payload with an adaptor. The Ariane 5G Plus had minor improvements including extra fuel and additional batteries and tank insulation to the upper stage to allow restarts. The maximum GTO payload was 6,950kg.

The new ECA variant was a major change. It used a more powerful Vulcain 2 as the core stage engine, the addition of 1,600kg of solid propellant in the boosters, and the addition of 5,000kg more LOx in the first stage by moving the tank bulkhead. A new cryogenic ESC-A upper stage used the HM-7B engine which burned LOx/Liquid Hydrogen. This rocket could carry 9,100kg to GTO as a dual payload. A fuller description is below.

Two sub-variants the Ariane 5 GS and the Ariane 5 ES were added to the family. The Ariane 5 GS had a modified Vulcain 1 engine which used the propellant pump system from the Vulcan 2 to match the propellant ration of the modified tank structure of the new core stage. The Ariane 5 GS went back to the EPS upper stage from the Ariane 5G Plus. The rocket had a dual GTO payload of 7,000kg. The Ariane 5 ES again used the EPS upper stage but with the Ariane 5 ECA main stage. The rocket could carry 8,000kg to GTO and 21,000kg to LEO.

The Ariane 5 ECA, which is currently used for the majority of Ariane missions (namely to GTO), had its first launch on 11 December 2002. The launch failed due to a first stage failure caused by a coolant pipe cracking on the engine. The rocket has not had a failure since that date.

Fig. 4.3-1 The Ariane 5 ECA launch vehicle lifts off on flight VA221

Courtesy: Arianespace

Technical specifications

The Ariane 5ECA has a configuration that consists of an EPC (Etage Principal Cryotechnique) core stage to which two EAP (Etage d'Accelerator a Poudre) strap-on solid-propellant boosters are fastened, with an ESC-A (Etage Superieur Cryogenique-A) installed atop the EPC.

The two EAP solid-propellant boosters provide the majority of the Ariane V's lift-off thrust at 7,080kN each at Sea Level, utilizing large segmented solid rocket engines designated MPS (Moteura Propergol Solide). The engines consist of seven steel sections that combine to form three propellant sections per booster. The lower two segments are manufactured at the launch site, with the smaller upper segments being fabricated in Italy. The booster profile is such that the thrust generated is reduced during the time that maximum dynamic pressure is experienced in flight, with the result that the core main engine does not need to be throttled. A blow down hydraulic nozzle gimbaled system provides attitude control in pitch, yaw and roll while the solid-propellant boosters are burning.

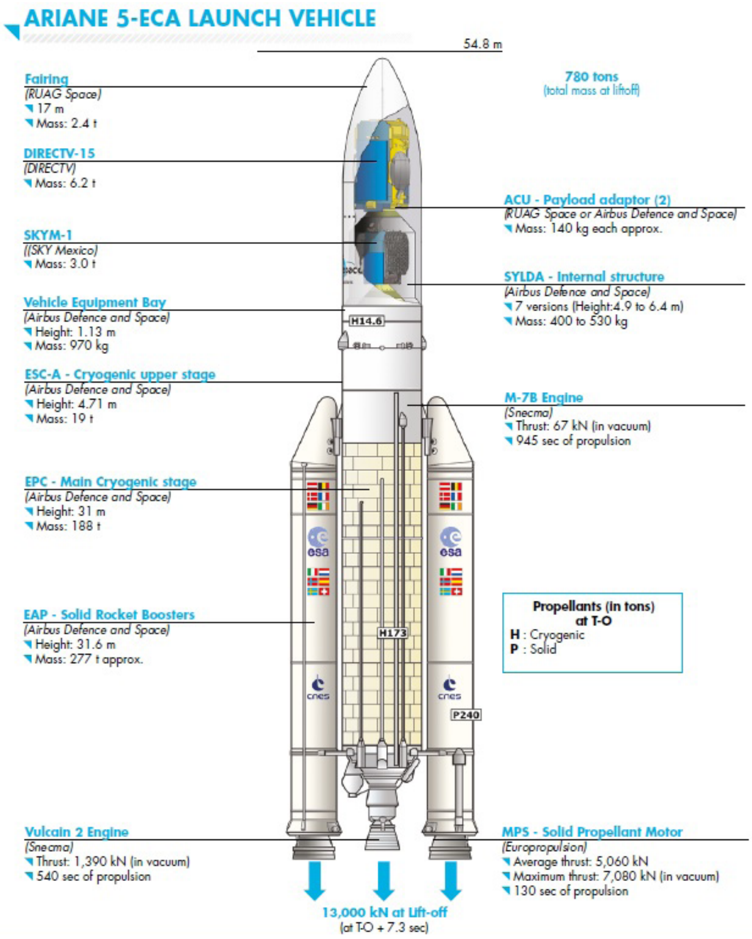

Fig. 4.3-2 Diagram for Ariane 5 ECA flight VA223 showing DirecTV-15 loaded above SkyMexico-1.

Courtesy: Arianespace

The cryogenic core stage is an aluminium semi-monocoque structure powered by a single Vulcain 2 engine of 1,390kN thrust in vacuum. It is attached through a thrust frame to the aft dome of the lower (liquid hydrogen) tank that transmits the thrust of the main engine and solid-propellant boosters. An upper inter-stage skirt provides a second attachment point for the boosters as well as housing the first stage electronics and providing an interface to the second stage.

A helium pressurised open-cycle hydraulic system enables pivoting of the Vulcain 2 engine about its gimbal joint, providing attitude control in pitch and yaw. After the boosters have been jettisoned, for the rest of the flight, roll control is enabled by a hydrazine attitude control system installed in the Vehicle Electronics Bay (VEB). This latter system provides three-axis control during coasting periods and during payload deployment.

The ESC-A second stage uses a 67kN (vacuum) HM-7B LOx/liquid hydrogen rocket engine from the Ariane 4 launch vehicle, together with new aluminium propellant tanks. The LOx (liquid oxygen) tank is semi-concealed within the liquid hydrogen tank.

The launcher's avionics contains two redundant Inertial Reference Systems (IRS), which provide navigational data to the on-board computers that calculate guidance commands and event timing. Each IRS consists of three ring laser gyros and four accelerometers. The VEB also contains telemetry, power distribution and flight termination systems.

The launcher's payload can be accommodated under two types of fairing, Type 01 with a length of 12.7m and Type 02 with a length of 17.0m, their inner diameters are identical at 4.57m each. There are two types of multiple launch carrier structures, Speltra and Sylda 5 (with smaller dimensions), which support the upper payload and encapsulates the lower payload during dual launches.

Payload capacity

The Ariane 5 ECA launcher has a total length of 54.8m to 59m depending on fairing configuration, its maximum diameter is 5.4m, with a total launch mass of 777 tons. It normally can launch up to 9.6 tons of payload (9.1 tons in a dual launch configuration) into GTO though this total has been recently stretched to above 9.9 metric tons including adapters.

Besides the Ariane 5 ECA, the Ariane 5 ES version has also been recently used for launching ATV-type cargo spacecraft to the ISS (representing four successful launches since 2011 up to 2015). As previously mentioned, the Ariane 5 ES version uses most of the main elements of Ariane 5 ECA design but substitutes the ESC-A upper stage with the restartable EPS upper stage from the Ariane 5G, in which storable liquid propellant is used. This Ariane 5 ES option can deliver up to 21,000kg of payload to LEO and could also launch dual payloads with a total mass up to 8,000kg to GTO.

Prelaunch preparations

Ariane 5 is launched from the ELA-3 launch pad in Kourou. The launcher's pre-launch preparation is featured with the parallel processing of separate components which is done in separate buildings. Vehicle checks are performed before and its payload is rolled out to the launch pad. This sequence reduces risk and allows for a maximum launch rate of ten Ariane 5 vehicles per year, although this rate has yet to be achieved. The fully assembled launch vehicle is transported to the prepared launch pad via a rail system.

Future prospects for Ariane 5

The estimated launch price for a fully loaded Ariane 5 carrying two satellites ranges from US$210 million to US$220 million. This puts it at the expensive end of the launch spectrum. However, the Ariane 5 ECA now has an envied reputation for reliability, which bestows the benefits of a very low insurance cost and the near guarantee of a successful delivery into orbit. So long as Arianespace can continue to "match pairs" of larger and smaller satellites to allow dual launches to take place, then the rocket will continue to compete, although it still requires a subsidy from ESA. Unfortunately, in order attract smaller satellites to allow this "pair matching" Arianespace need to give their operators the better end of the launch price deal. The new Ariane 6 design, is, in effect, a cheaper to produce Ariane 5, with much of the technology that was planned for the now cancelled Ariane 5 ME upgrade /5/.

Concluding comment

The Ariane 5 ECA is now a very reliable rocket but finds itself having to compete with much cheaper launch vehicles such as SpaceX's Falcon 9 v1.1 and Falcon 9R, and their heavier derivative, the Falcon 9 Heavy. These rockets, once proven, are likely to defeat the Ariane 5 ECA in the market. There is also a future commercial threat posed by the newly developed Russian Angara-A5, which will eventually replace the Proton-M, previously the main competitor to Ariane 5. As such, the Ariane 5 ECA will soon have to retire in favour of its closely related, but much cheaper to produce, successor Ariane 6.

5. LAUNCH VEHICLES EXPECTED TO BECOME OPERATIONAL BY 2020

New launch vehicles or systems considered for this section are those which can carry a payload of above 100kg to LEO, while having a convincing development schedule leading up to a firm maiden orbital flight before the end of 2020. These launch vehicles have the attributes of sufficient funding, available production capabilities and organizational arrangements, project development up to the level of hardware manufacturing (with completed tests for major components) and the existence of a clearly defined flight test schedule (which could even be begun without the completion of a successful first-time orbital mission).

Some new rocket designs expected to become operational within the next few years have been excluded from this section. The sub-orbital flight of the Russian Angara-A1.1PP launch vehicle, which was described in **Section 4**, is enough to consider it as operational, since this flight was the final in-flight verification combining all the comprising stages that had already been tested in previous orbital missions. Other 'new' rockets are really upgraded or close derivatives of current launch vehicles e.g. Antares 230, Vega-C, Shavit 3 etc. Thus, they have had their details covered in the previous section.

An exception to this rule is the Falcon 9 Heavy which, while using elements of previous Falcon 9 launch vehicles, has such a significant performance increase that is has been classed as an imminently operational new launch vehicle and has thus been included in this section. Similarly, the GSLV Mk 3 is classed as a significantly different new vehicle compared to past GSLV designs, despite using some elements of previous GSLV rockets.

Therefore, with the above mentioned definitions noted the following list of launch vehicles and systems have been included in this section. Only one is air-launched (LauncherOne), the rest are vertically launched. Only one will eventually have reusable rocket stages in the near term (Falcon 9 Heavy):

- Ariane 6
- Athena Ic/IIc
- Cyclone-4
- Falcon 9 Heavy
- GSLV Mk.3
- H-3
- LauncherOne
- Long March-5/-6/-7 family
- SLS
- Spark (Super Strypi)
- VLS/VLM

They are described briefly in in following **Sub-sections**.

5.6 GSLV Mk.3 (India)

Fig. 5.6-1 The launch of the GSLV Mk.3 prototype on 18 December 2014.

Courtesy: ISRO

ISRO is currently introducing what is, in effect a new design: the new GSLV Mk.3 launch vehicle. This will equipped with a large liquid-fuelled core stage and augmented by two solid rocket boosters, which have been developed from the first stage of the Mk.3's predecessor, GSLV Mk.2 (described in **Sub-section 4.9**) /6/.

The GSLV Mk.3's first sub-orbital flight was completed successfully on 18 December 2014 with a dummy of a future manned re-entry capsule (**Figure 5.6-1**). This mission cannot be considered as the beginning of this launch vehicle's operation since it was a sub-orbital test flight and was therefore not representative of a typical flight for the GSLV Mk.3, which will mainly be intended for GTO missions.

The GSLV Mk.3 is a three-stage launch vehicle. Its operational version has a lift-off mass of 630.58 tons and a total length of 43.43m, with a payload capacity of 10 tons to LEO, or 4,000-5,000kg to GTO. The launcher consists of a liquid-propellant core unit and two powerful strap-on solid-propellant boosters.

The S200 strap-on solid-propellant boosters (that are also known as LSB=Large Solid Boosters) have a three-section steel structure, containing an HTPB-type solid propellant. The booster has a swivelling nozzle installed on a flexible bearing. The maximum thrust of the S200 is 5,150kN in vacuum.

The L110 main stage of the core unit is equipped with two Vikas-2 rocket engines, each with a thrust of 1,598kN tons in vacuum. They use a N2O4 and UH25 propellant (a mixture of 75% UDMH with 25% hydrazine hydrate) stored in steel tanks. The engines have a turbo-pump propellant supply system and are installed in gimballing suspensions.

The upper stage of the core unit will eventually be a C25 cryogenic stage, but it was not ready for the first test launch of the Mk.3, so a C25X dummy was used instead. The standard version of the C25 will be equipped with a single CE-20 open cycle restartable LOx/liquid hydrogen rocket engine, with a thrust of 186kN in vacuum. Attitude control will be provided by two vernier engines during the active legs of flight, and with nozzles using cold gas during the passive legs.

The CE-20 engine is the most problematic component of the C25 stage and of the whole launcher. Its current incomplete state caused the requirement for a stage dummy in the first launch of the Mk. 3, which in turn meant that this flight could not be classed as a fully representative launch. However, certain ISRO specialists are convinced that the engine will be ready for the second flying example of the GLSV Mk.3 in 2017.

The launcher's digital control/guidance system is based on on-board computers and an inertial guidance platform. It is accommodated in an instrument compartment that is installed atop the C25 stage. A two-shell nose fairing is made from aluminium alloy with sound proofing protection.

ISRO forecasts that the GSLV Mk.3 will begin regular operations in 2017. It is planned to be operated in parallel with the GSLV Mk.2, providing a rate of around two missions a year for both for national launch vehicles, which will be used for non-commercial missions (interplanetary probes and manned spacecraft) and commercial launches to GTO.

Concluding comment

GSLV Mk.3 will need a series of successful launches to give confidence to potential clients and insurers. Once this is achieved then the GSLV Mk.3, with its ability to put 4,000-5000kg satellites into GTO, could become a major competitive force on the world stage. This assumes that US satellite technology launch restrictions will not get in the way.

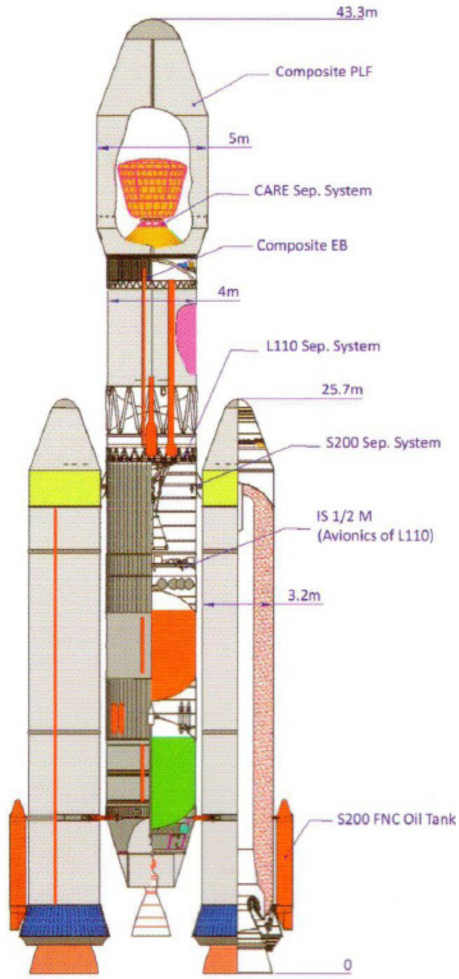

Fig. 5.6-2 The main internal design features of the GSLV Mk.3 launch vehicle.

Courtesy: ISRO

6.5 Reaction Engines Skylon

Fig. 6.5-1 Artistic rendering of Skylon

Courtesy: Reaction Engines

Reaction Engines' Skylon /6/ /7/ /8/ is currently the only SSTO vehicle under serious consideration for development. Providing a capability that leapfrogs the expendable launch vehicles and reusable two-stage-to-orbit launchers in terms of payload launch costs and launch availability, this spaceplane offers aircraft style runway operations and very flexible launch opportunities.

A standard Skylon mission would see a payload of up to 15 metric tons loaded into the Skylon payload bay in a spaceport loading area, much like a conventional cargo aircraft. Skylon would then be towed out to the end of a runway, filled with its propellants and then take off like an aircraft, climbing on an air-breathing ascent before transitioning to rocket mode to achieve LEO. It will then deliver its payload, such as a satellite and/or transfer stage, or structural load. Skylon would then prepare to de-orbit, re-entering Earth's atmosphere and, after re-entry, follow a gliding descent back to its spaceport of origin.

Skylon's advantage is that it uses an air-breathing rocket engine to reduce the amount of oxygen needed to attain orbit, with the benefit of this resulting in a larger payload. The air-breathing rocket engine technology uses a pre-cooler to deeply cool, but not liquify, incoming air before injecting that air into the combustion chamber with hydrogen fuel. It uses this air-breathing mode of operation from take-off until high in the atmosphere. At an altitude of 26km (almost three times the altitude of a commercial passenger jet) and at a hypersonic speed of Mach 5.4, Skylon transitions to pure rocket mode, where it uses its on-board supply of oxygen for the remainder of the ascent to orbit.

Currently, development and testing work has focused on the innovative engine that powers Skylon, the SABRE (Synergetic Air Breathing Rocket Engine) rather than on the construction of the launch vehicle itself.

Skylon will have two engine nacelles, one on the tip of each wing, each containing a SABRE. Development work has seen successful initial ground testing of the precooler heat exchanger – the most efficient heat exchanger ever built – down to cryogenic temperatures. Other work has included designing altitude compensating expansion/deflection rocket nozzles, testing of a liquid oxygen cooled combustion chamber, as well as wind tunnel testing of the design and comprehensive trajectory and re-entry modelling.

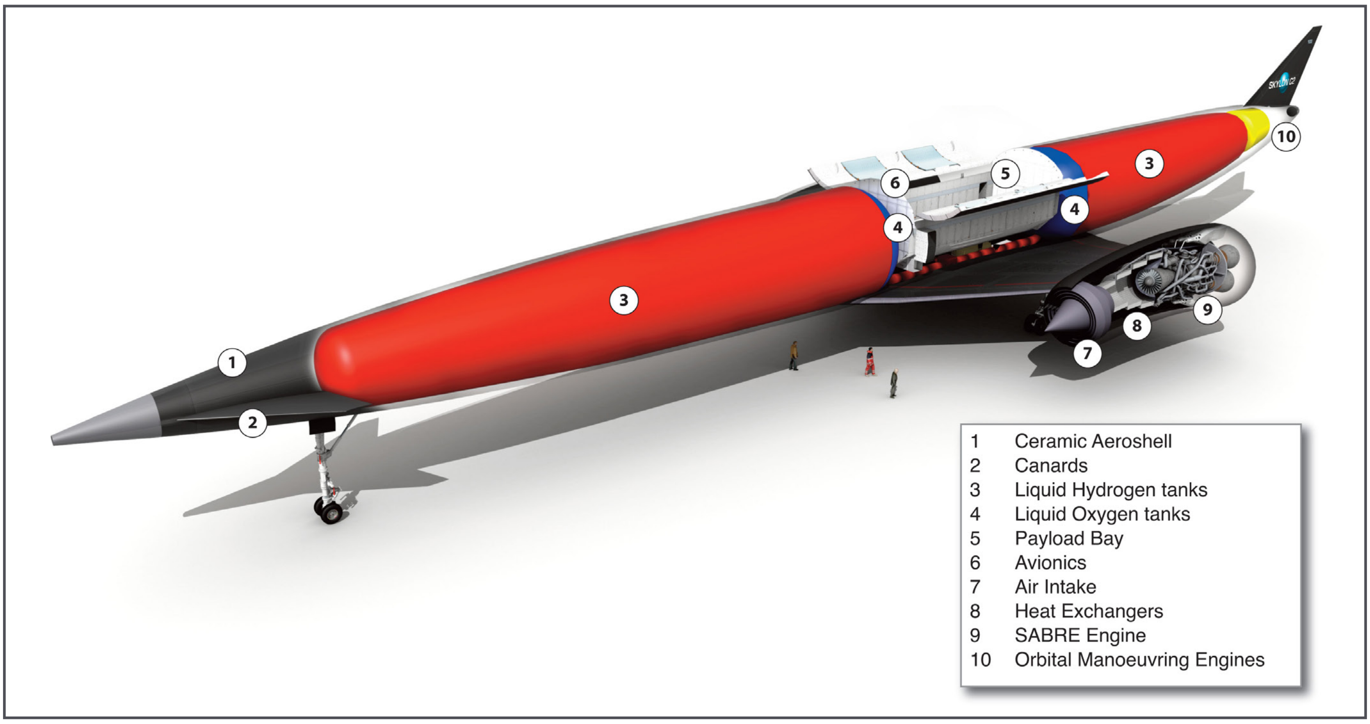

Fig. 6.5-2 Cutaway of Skylon

Courtesy: Reaction Engines

The Skylon spaceplane research has European Space Agency and UK Government support and it may become a follow-on launch vehicle to the Ariane series.

Concluding comment

Skylon is the “great space hope” for low cost regular access to orbit for larger payloads. While funding from the UK and ESA is being used to build and test some of the key elements of the hardware – mainly the SABRE engine design, there is unlikely to be any progress on the launch vehicle until the Ariane 6 project is completed. However, Skylon is positioning itself to be a likely successor to Ariane 6 – assuming it is built in Europe and not in the USA, which has also taken note of the concept’s potential.

7.1 DARPA Boeing ALASA

Fig. 7.1-1 Boeing's ALASA concept involves the air launch of a rocket from an F-15E

Courtesy: DARPA

In 2011-2012, the US Defense Advanced Research Projects Agency (DARPA) held a competition for concepts on a quick launch system called ALASA - Airborne Launch Assist Space Access. The target performance for the programme is a launch vehicle able to launch a 45kg payload into low Earth orbit for less than US$1 million and within 24 hours of notice. In March 2014, Boeing won the initial competition against two other teams and has been awarded a contract worth US$104 million to move to Phase 2 for its design.

The concept uses a 7.3m long rocket dropped from an F-15E fighter jet at 40,000 feet. It will be powered by a monopropellant, a combination of nitrous oxide and acetylene mixed together in one propellant tank slightly below room temperature. While Boeing has not promised the cost performance of the target, it has announced that it is aiming to reduce launch costs for this size of payload by at least 66%.

The ALASA rocket does have a unique configuration in having four rocket engines forward-mounted. This configuration allows just the fuel tank stages to fall away as the engines fire all the way to orbit. In order to avoid impingement by the rocket engine's very hot plume, the engines are mounted away from the rocket with thrust inefficient nozzles canted (angled) away from the body.

In December 2012, DARPA announced that the ALASA program would launch a constellation of DARPA imaging microsatellites. DARPA is also developing a Small Air Launch Vehicle to Orbit (SALVO) as a test vehicle for ALASA.

Concluding comment

The concept, if developed, would have ASAT (Anti-satellite) potential with some speculating that the SALVO project is a front for such a device. An ASAT missile system developed in the late 1970s was also launched from an F-15. Getting down to a cost of US$1 million a launch is a tall order for this project. The mono-propellant system uses an explosive mixture in its tankage resulting in a high risk of loss of vehicle and carrier aircraft. Nevertheless, the engines-forward tank-behind configuration is an interesting one. However, even if it works, it is unlikely to be offered on a commercial basis for several years.

8. COMMERCIAL ORBITAL SPACEPORTS

While a full listing of the world's launch sites used by orbital launch vehicles is shown on the inside cover, the definition of what constitutes a commercial spaceport is a difficult one. The world's major launch sites are nearly all used for commercial launches in addition to their government and military spaceflights, those launch sites whose commercial launches only constitute a very small proportion of their activity are not included on this list.

Thus, in this report, Cape Canaveral, Vandenberg and Baikonur are included because private launch companies pay for the use of the site or its launch facilities, and provide a significant portion of the flights from these launch sites.

While the Russian launch sites at Plesetsk and Yasniy (Dombarovskiy), the Indian launch site at Sriharikota, the Chinese launch site at Xichang, and the Japanese launch site at Tanegashima, have launched significant numbers of commercial or commercially shared launches over the years, they are primarily used for military or governmental launches and are thus deemed not to be commercial space ports.

For the time being, NASA's Kennedy Space Center (KSC) has only been mentioned in the Cape Canveral entry. However, it will soon be a commercial spaceport in its own right, once SpaceX Falcon 9 launches start using the former Space Shuttle launch pad, LC-39A. The number of commercial launches will significantly exceed the number of NASA SLS launches from the neighbouring former Space Shuttle launch pad LC-39B.

Some commercially used launch sites/facilities with doubts over their future use have also not been included. An example of this type is the Sea-Launch 'Odyssey' plaform even though it has previously launched many commercial flights from an equatorial position in the Pacific.

With the development of sub-orbital tourism and microgravity research vehicles has also come the advent of specially devised self-proclaimed "commercial spaceports". These have been designed specifically for commercial use by different launch operating companies, much in the same way as an airport is used by multiple airlines.

While these will be mostly used for suborbital spaceflight and thus have not been included, some are being readied for commercial orbital launch opportunities. The commercial spaceports capable of operating orbital launches will usually have a launch corridor which is safe/available/feasible and which has predefined drop zone (normally over the ocean) for expended stages, with landing zones/ships for reusable stages.

Fig. 8.0-1 KSC will soon be a commercial spaceport in its own right once SpaceX Falcon 9 rockets begin launching from Pad LC-39A (top right, near the coast)

Courtesy: NASA